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July 1971

IVORY CORAL APPLICATIONS AND DIAGNOSTICS (U)

Aeronomy Corporation

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Rome Air Development Center
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IVORY CORAL APPLICATIONS AND DIAGNOSTICS (U)

S. A. Bowhill

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

RADC Project Engineer

Frederick C Wilson

Contract Engineer

ABSTRACT (U)

(S) Comments on possible defense applications of artificial spread F (ASF) and wide-band attenuation (WBA) are discussed and related to a possible five-year plan for the IVORY CORAL program. The preliminary results of an airborne experiment are given, the purpose of which was to determine the feasibility of a conjugate-point experiment on ionospheric heating.

TABLE OF CONTENTS (U)

1. POSSIBLE DEFENSE APPLICATIONS OF IVORY CORAL PHENOMENA (U)

1.1 Introduction (U)

(S) The purpose of this section is to discuss the outstanding features of the phenomena of artificial spread F (ASF) and wide-band attenuation (WBA) and their relevance to defense applications.

(S) The ionosphere is a generally homogeneous, horizontally stratified plasma with relatively predictable characteristics. Its relative horizontal stratification permits its use for long-range communications and DF and OHD. Its relative uniformity permits radar and space telemetry systems to look through it without degradation. On the other hand, this uniformity prevents its use for backscatter communications except under special circumstances (e.g., meteors) which require large antennas.

(S) The potential applications of IVORY CORAL arises from the reversing of all these previous properties of the ionosphere. ASF destroys the uniformity and horizontal stratification of the ionosphere, and creates irregularities (probably field aligned) that can sustain backscatter at HF. This effect is initiated with substantial heating transmitter powers, but so rapidly that only 10^6 Joules are involved for an effect that extends over hundreds of km.

1.2 Useful Features of IVORY CORAL (U)

(S) Table 1 outlines features of ionospheric heating which distinguishes it from other phenomena that could have similar applications. The features 1, 2, and 3 are basic to the phenomenon. Its random microstructure gives it potential disruptive capabilities for DF, communications, OHD and radar. The organized orientation of the microstructure gives potential for highly aspect sensitive

Table 1

Specifically useful features of the IVORY CORAL phenomenon (U)

Basic features

1. Random microstructure
2. Organized microstructure orientation (field-aligned)
3. Restricted and predictable geographic extent

Convenience features

4. Instant initiation of effect
5. Relatively portable installation
6. Effect can be produced remotely
7. Economic to maintain continuously

Strategic advantages

8. Immune to countermeasures
9. Politically unassailable

backscatter communications (namely, illuminating only a restricted area on the ground). Its restricted geographic extent permits confining its effects to specific paths or theaters.

(S) For many systems applications, the convenience of producing the phenomenon is critical, and relevant features are shown in Table 1 as items 4 through 7. The effect appears ~~within~~ seconds of initiation of O-mode heating; a relatively portable (i.e., capable of being carried in semi-trailers) installation has been designed; and it is known that the effect can be produced using obliquely-directed arrays. It is possible, in addition, that it may be produced at the magnetic conjugate point. Lastly, there is no reason why the effect should not be sustained on a continuous basis as required.

(S) Finally, it has two features which may prove overwhelmingly advantageous (items 8 and 9). While it is produced by a heating transmitter, there is almost certainly no way to remove it short of an atomic explosion in the upper atmosphere. Furthermore, since no additional ionization is produced, there is no reason that any friendly, neutral or hostile country could object to having its effect produced over its territory. It is therefore felt to be politically unassailable.

(S) Briefly, one can compare IVORY CORAL with other phenomena or devices that have overlapping potentials. For disruptive purposes, an atomic explosion has all features of Table 1 except numbers 7 and 9. A barium cloud has all features except 4, 7 and 9. For communication purposes, a communication satellite lacks feature 8.

1.3 Possible Applications (U)

(S) The most likely potential applications of ASF and WBA are listed in Table 2. While space does not permit a detailed discussion of each of them, the most pertinent points are given below.

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Table 2

Applications requirements related to critical ("C") and significant ("S") questions (U)

Applications requirement	Scattering Model 2.1	2.2	2.3	2.4	2.5	Yield Optimization 3.1	3.2	3.3	3.4	3.5	3.6	Basic 4.1	4.2
1. Long-range extended-MUF communications	C	C	C	C	C	S	C	S	C	S	S	C	
2. HF intratheatre communications	C	C	C	C	S	S	S	S	C	S	S	S	
3. Long-range air-ground communications	C	C	C	C	C	S	C	S	C	S	S	C	
4. Agent communications	C	C	C	C	C	S	C	C	C	C	C	S	
5. VHF tactical communications	C	C	C	C	C	C	C		C	C	C	S	
6. Interception of hostile signals	C	C	C	C	C	C	C	C	C	C	C	C	
7. DF bearing deformation	S	S	S	C		C	S	C	C	C	C	S	
8. OHD disruption	C	S	C	C		C	C	C	C	C	C	S	S
9. Communications disruption	C	S	C	C		C	C	C	C	C	C	S	S
10. Offensive radar disruption	C	S	S	C		C	C	S	C	C	C	S	S
11. IR observable contamination				S		C	C	C	C	C	C	C	C

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(S) Table 2 also connects the applications with a set of critical questions (Table 3) which will need to be answered before a determination can be made of the exact applicability of ASF and WBA.

(S) 1. Long-range extended-MUF communications--existence of an HF path with extended MUF has already been demonstrated. This opens up an essentially interference-free region for fixed-station communications.

(S) 2. HF intratheater communications--high cross sections have been demonstrated for ASF backscatter at frequencies to 30 MHz. Within a theater large antennas would not be needed for voice communications, and the effect will be confined to a limited region.

(S) 3. Long-range air-ground communications--particularly for peacetime uses there is obvious application for air-ground communications.

(S) 4. Agent communications--the high cross section and "instant-on" capability will permit HF communications from agents in hostile territory without the necessity for them to radiate in what would normally be regarded as an HF communication band.

(S) 5. VHF tactical communications--the frequency variation of the cross section above 30 MHz has not been explored at all. Certainly, some VHF scatter must take place (although it is known not to extend to 150 MHz). Therefore, one cannot rule out the possibility that ASF can be applied to VHF tactical communications (e.g., in a beachhead situation).

(S) 6. Interception of hostile signals--signals propagated totally within hostile territory, which would not normally propagate to our sensors, may be made to do so by increasing the effective MUF for the path.

(S) 7. DF bearing deformation--the quality of enemy bearing determinations on our HF transmitter can be greatly harmed by systematically distorting the ionospheric layers over the propagation path. The potential of IVORY CORAL in this regard is not known.

Table 3

Recapitulation of critical questions (U)

Scattering model questions (U)

(S) 2.1 What is the size of the microstructure of the artificial spread F (ASF) ionization variation; for example, 2 km or 1 m?

(S) 2.2 Are the ASF irregularities field aligned, and do they extend through the entire F region?

(S) 2.3 What is the rate of movement and time change of the ASF irregularities?

(S) 2.4 What is the geographical extent of the ASF?

(S) 2.5 Under what conditions is the ASF scattered signal subject to multipath effects?

Yield optimization questions (U)

(S) 3.1 How great an effect can be produced at substantial distances (say, 1000 km) from the heating transmitter?

(S) 3.2 Does the occurrence of wide-band attenuation (WBA) enhance the yield of ASF for a given heating power?

(S) 3.3 Does the ASF disturbance over Platteville produce a similar disturbance at the magnetic conjugate location in the southern hemisphere?

(S) 3.4 Does the ASF yield depend on the latitude in which the heating is taking place?

(S) 3.5 Can the ASF yield be improved by focusing the RF energy into the ionosphere?

(S) 3.6 Under given ionospheric conditions, how does the ASF yield depend on frequency?

Basic phenomenology questions (U)

(S) 4.1 Is the phenomenon normally described as "natural occurring spread F" actually a manifestation of ASF from communication or broadcast HF transmitters?

(S) 4.2 What is the mechanism for WBA, and how does it relate to enhanced IR emission?

(S) 8. OHD disruption--the effects of ASF on OHD signals have not been fully tested because of the lack of an optimum experimental arrangement. If this effect could occur, it could have both offensive and defensive applicatio[illegible]

(S) 9. Communications disruption--it is known that fast fading can be produced in an ionospheric reflection by ASF. Enemy communications may well have sufficient unacceptable degradation from this effect, though the details are not known.

(S) 10. Offensive radar disruption--no experiments have yet been made on the degradation of position determination for field strength for a VHF signal propagated through ASF. Suitable experiments are sorely needed.

(S) 11. IR observable contamination--it is known that 1.27μ radiation is enhanced probably due to WBA. The details of this phenomenon are not understood.

1.4 Significant Questions (U)

(S) Obviously, the wide scope of the applications listed in the previous section implies an urgent need for systems studies. These studies cannot be initated unless certain critical questions are answered (see Table 3). They pertain to establishment of a realistic scattering model; determining the conditions under which optimum yield of ASF and WBA are obtained; and ascertaining the basic phenomenology of ASF and WBA.

1.5 Conclusion (U)

(S) It cannot be emphasized too strongly that it is premature to conclude that ASF (or other IVORY CORAL phenomena) definitely do or do not have critical defense applications. The present model of ASF is not sufficiently good to tell. However, there is a strong likelihood that such a critical defense application exists. Therefore, it is recommended that the highest priority be given to ascertaining for certain which of the applications in Table 2 are important for national defense.

2. FIVE-YEAR PLAN FOR IVORY CORAL APPLICATION STUDIES (U)

2.1 Introduction (U)

(S) Applications of the IVORY CORAL phenomenon seem to involve four categories of effect:

1. Scattering of radio waves in the disturbed region.
2. Distorted transmissions of radio waves through the distrubed region.
3. Infrared emissions from the disturbed region.
4. Micropulsation signal generation in the disturbed region.

So few diagnostic experiments have thus far been carried out on the IVORY CORAL phenomenon that systems studies required to evaluate the significance of these applications cannot yet be carried out. Specifically, the scattering and transmission effects on radio waves need a model of the phenomenon which is not at present available; this is dealt with in Section 2.2. Since the transmitters necessary to produce the disturbances are large and cumbersome, the yield of disturbance in terms of disturbing power is of crucial importance; this is treated in Section 2.3. Optical or ELF emissions from the disturbed region cannot be extrapolated without an understanding of the basic phenomenology discussed in Section 2.5. In Section 2.5, a realistic list of experiments is given to answer the questions raised in Sections 2.2, 2.3 and 2.4, together with a brief description of each and an estimate of the time required to achieve the results. Finally, Section 2.6 gives a series of milestones at which decisions can be made regarding the various items (though the results of the experiments cannot, of course, be predicted ahead of time).

2.2 Scatter and transmission model (U)

(S) The principal results of radio-propagation experiments on the IVORY CORAL phenomenon may be summarized as follows (these results apply primarily to O-mode heating):

1. Near vertical incidence, multipath and scattering effects are seen, similar to those associated with naturally-occurring spread F. This "artificial spread F" (ASF) seems to exist through the entire F region, over a north-south extent of at least 200 km.

2. Oblique-incidence HF backscatter has been seen from a southerly direction with a cross section of 10^9 m^2 at 13 MHz, and 5 x 10^7 m^2 at 30 MHz. The scattering irregularities appeared to be moving about 25 m/s toward the south. For the same geometry, no backscatter was seen at UHF. Similar HF effects in an east-west direction have been seen with the MADRE radar.

3. HF propagation over a non-great-circle path has been found at frequencies above the great-circle MUF; the additional signal appearing to have a group delay/frequency characteristic similar to an oblique-incidence path but with enhanced MUF.

(S) All of the above phenomena were for the Platteville site. No ASF irregularities, or scattering associated with them, have yet been observed at Arecibo (see Section 2.3).

(S) The following questions need to be answered before a realistic scattering model of ASF can be prepared for systems studies:

(S) 2.2.1 What is the size of the microstructure of the ASF ionization variation in the disturbed region; for example, 2 km or 1 m?

(S) It must be emphasized that backscattering experiments by themselves cannot answer this question. Discussion has centered around two types of

scattering models, the "overdense column" model typical of the SECEDE barium releases, and the Booker "weak scatter" model in which scattering occurs at sharp gradients of ionization. To explain the observed frequency variation of backscatter cross section requires a microstructure of about 1 m. It does not seem likely that so small a structure size can be sustained against even the relatively slow plasma diffusion across the magnetic field. The present author has recently developed an alternative approach, the "ray-diffusion" model, in which backscatter occurs as a result of the gradual deviation of rays passing through a succession of much larger irregularities. Since the backscatter cross section in this case is proportional to $\exp(-kf^4)$, it is well capable of explaining the observed variation with frequency without the requirement of very small structure size.

(S) Because the intensity of the ASF electron-density fluctuations and the size of the microstructure affect the cross section in a similar way, backscatter observations are far from ideal to determine either of these quantities. Much more satisfactory is a transmission experiment through the disturbed region at a frequency high enough to avoid multipath effects. The structure size of scintillating signals at the ground is identical with that in the disturbed region, permitting a determination of its morphology. A proposal for this experiment has been prepared by Bowhill, et al. (1971). An additional point favoring this experiment is that the results obtained will be directly applicable to a radar-transmission model of the disturbed region, needed for degradiation studies.

(S) Other techniques for determining microstructure include measurements by on-board probes on orbiting satellites at altitudes low enough to pass through the F region; and measurements by rocket probes fired through the disturbed region. Generally speaking, the relationship between the speed of an orbiting satellite and its rate of data collection do not permit its determining

microstructure scale sizes less than about 1 km. Rocket firings are not thought to be possible in the Platteville region, but can be considered with a mobile facility.

(S) 2.2.2 Are the ASF irregularities field aligned, and do they extend through the entire F region?

(S) On physical grounds, the probable answer to this question is "yes" on both counts, in view of the relative ease of movement of ionization along the lines of the earth's magnetic field. However, a definite answer is essential because of the very strong aspect sensitivity associated with monostatic or bi-static scatter from field-aligned ASF. It is suggested that a two-pronged attack be initiated on this problem. Firstly, the satellite transmission experiment alluded to under the previous question should be instrumented so as to measure the orientation and aspect ratio of the ASF irregularities as well as their size; this will require a net of three receiving stations. In addition, the aspect sensitivity of bistatic ASF scatter should be explored at a number of frequencies by observing the intensity of the signal scattered by the ASF from a ground-based transmitter to an airplane equipped to survey the regions at which the scattered signal can be observed. This would also serve as a check on the frequency characteristics of the scattering deduced from its microstructure.

(S) 2.2.3 What is the rate of movement and time change of the ASF irregularities?

(S) This question, important for modelling communications applications of the phenomenon, can be answered by a satellite transmission experiment on a geostationary satellite, and confirmed by the bistatic airplane experiment indicated under 2.2.2.

(S) 2.2.4 What is the geographical extent of the ASF?

(S) Based on the power density calculations for the Platteville experiment, a horizontal extent of about 100 km was estimated for the disturbed region. In

connection with another application (see Section 2.3), a survey has been carried out of the distribution of ASF in a magnetic north-south meridian plane through Platteville. The results of this experiment (see Section 3 of this report) show that the ASF in fact extends over more than 200 km. Obviously, it is vitally important for modelling to know the precise extent of the disturbed region and the volume of scatterers involved, under a variety of experimental conditions. Therefore, the airborne ionosonde experiment just described (being the simplest experiment to provide this information) should be continued as part of the systematic survey of the disturbance geography.

(S) 2.2.5 Under what conditions is the ASF scattered signal subject to multipath effects?

(S) For communications and D/F purposes, it is very important to know if multipath effects are present. Examining the time or space variability of the signal (as is well known) will not resolve the multipath problem; a large-aperture system is required. It is suggested that a synthetic aperture approach be used, as described in Section 4 of this report.

2.3 Optimization of Yield (U)

(S) In any application of ASF, its usefulness is proportional to the scattering cross section; namely, to the square of the electron-density fluctuation produced. The greater this "yield" can be made (or, conversely, the smaller the heating transmitter that is needed) the more likely it is that useful applications will be found.

(S) At present, yield or threshold information for ASF is very limited. The power threshold at Platteville appears to be about 100 kW; and no quantitative data are available for its variation with frequency. The following appear to be the most significant questions:

(S) 2.3.1 <u>How great an effect can be produced at substantial distances (say, 1000 km) from the heating transmitter?</u>

(S) Experiments of this kind are already under way at Platteville; however, in order for them to be maximally useful, they should be combined with an airborne sounder exploration of the extent of the ASF region. Use of one or two isolated sounders, unsupported by aircraft sounders may not prove rewarding.

(S) 2.3.2 <u>Does the occurrence of wide-band attenuation (WBA) enhance the yield of ASF for a given heating power?</u>

(S) When the F region is heated with ordinary polarization at a frequency below foF2, the ordinary wave from a separate vertical incidence sounder is heavily absorbed between the heating frequency and foF2. This phenomenon, wide-band attenuation (WBA), is thought to be associated with excitation of a parametric instability in the F region (similar to that observed in laboratory plasmas). The same phenomenon has been observed at Arecibo in an enhancement of the plasma line of incoherent scatter at 400 MHz. The irregularities associated with WBA are likely to be distinguishable from those of ASF by the high Doppler velocity associated with the (approaching the ion-acoustic velocity). Now, any mechanism which produces additional absorption of the heater transmitter energy can be expected to increase its yield of ASF. Careful quantitative studies are needed to this effect, including accurate measurements of the reflection coefficient versus frequency in the range of interest. Such experiments should be conducted both at Platteville and Arecibo (see Section 2.4.2).

(S) 2.3.3 <u>Does the ASF disturbance over Platteville produce a similar disturbance at the magnetic conjugate location in the southern hemisphere</u>

(S) This possibility has been discussed briefly in a previous document (Bowhill, <u>et</u> <u>al</u>., 1971). Whether the effect occurs will depend on whether

strongly irregular electric fields are associated with ASF irregularities. The possibility that the conjugate ASF can be produced, and that it has defense applications, cannot be ruled out. The magnetic conjugate point to Platteville is located in the South Pacific. Obviously it would be much more convenient to set up a sounder at a conjugate point on land; unfortunately, the only other heating transmitter available, at Arecibo, has not so far produced ASF. Therefore, the most feasible approach seems to be to use an ionosonde-equipped aircraft, based perhaps in Argentina, and flying out to the conjugate point and back. The aircraft has already demonstrated its capability to detect and map ASF at the northern location; it should be even less difficult in the southern point due to the greatly reduced level of ground-based RF interference.

(S) 2.3.4 Does the ASF yield depend on the latitude in which the heating is taking place?

(S) While the physical mechanism for the production of ASF is not understood (see Section 2.4), it seems possible that they are produced by pushing a naturally-occurring amplification effect into the region of instability. It may well be, therefore, that the evident difference in ASF behavior between Platteville and Arecibo can be attributed solely to the difference in latitude; the higher latitudes being less stable against heating. For systems applications it is obviously important to understand this effect. The only feasible way to do so is to construct a mobile heating facility and map the ASF yield versus latitude in a series of field experiments. The airplane sounder could prove useful in this part of the program.

(S) 2.3.5 Can the ASF yield be improved by focusing the RF energy into the ionosphere?

(S) If a 10-unit mobile facility is constructed it is not restricted to a compact antenna array such as that used at Platteville. Wide separation of the

elements, and use of a larger, simpler antenna with each, would permit a much higher energy density in the ionosphere over a more limited spatial extent; perhaps thereby giving a much greater yield in terms of scattering cross sections. This possibility should by all means be explored.

(S) 2.3.6 Under given ionospheric conditions, how does the ASF yield depend on frequency?

(S) The HF transmitters at Platteville and Arecibo are both restricted to fixed frequency during a given experimental run, because of mechanical and electrical considerations of the design. Therefore, it is necessary to wait for ionospheric conditions to change in order to follow the effects of changing the ratio of heater frequency to the F2-layer critical frequency. This makes it extremely difficult to estimate the effects of frequency on yield. Certainly, there is strong need for a transmitter facility with rapid-frequency-change capability which can explore the possibility of increasing the ASF yield by rapidly changing the heater frequency to its optimum value.

2.4 Basic Phenomenology (U)

(S) While it is not the purpose of this document to suggest a program of basic research, there are certain basic questions about the IVORY CORAL phenomenon which impinge strongly on defense applications. Some, but not all, of these can be answered by suitably-planned experiments. For example:

(S) 2.4.1 Is the phenomenon normally described as "naturally-occurring spread F" actually a manifestation of ASF from communication or broadcast HF transmitters?

(S) As far as I know, no one has explored the occurrence of natural spread F near large HF broadcast transmitters (such as those operated by VOA). A world-wide survey of spread F occurrence in relation to such transmitters would not be too hard; even better would be special experiments on ASF mounted over a range of

latitudes, using cooperative transmitters and specially located ionosondes (or, better, an aircraft-borne sounder).

(S) 2.4.2 <u>What is the mechanism for WBA, and how does it relate to enhanced IR emission?</u>

(S) If the IR signal associated with WBA seems to have military applications, optimization of its yield will be essential. Much more study will be needed, however, of the basic mechanism of WBA and the non-Boltzmann electron disturbance associated with it, before such yield studies can be made.

(S) If the physics of this phenomenon proves hard to unravel with these experiments alone, it may prove desirable to use the mobile facility to study the electric field and particle energies of WBA with rocket probes.

2.5 <u>Experiments Required (U)</u>

(S) The various questions developed in Sections 2.2, 2.3 and 2.4, answering which is vital to determining possible system applications of IVORY CORAL, are recapitulated in Table 4. The new experiments described in these sections as necessary to answer the questions in Table 4, are listed in Table 5. In this section, brief descriptions of the experiment are given, together with approximate time scales for their completion.

(S) 2.5.1 <u>Geostationary satellite transmission experiment</u>

(S) This experiment has already been fully described by Bowhill (1970). It involves location of a net of three receiving stations for the satellite ATS-V in the east central portion of Wyoming, 42.9 deg N, 104.3 deg W. The elevation angle of 44 deg for the arriving signal at 136.47 MHz will permit determination of the structure size and transmission characteristics with a simple interferometer system with a variable baseline of less than 1 km. While three receivers would be desirable, careful experimental planning could use as few as two. It should be possible to set up this experiment within approximately 3 months.

Table 4

Recapitulation of critical questions (U)

Scattering model questions (U)

(S)2.2.1	What is the size of the microstructure of the artificial spread F (ASF) ionization variation; for example, 2 km or 1 m?
(S)2.2.2	Are the ASF irregularities field aligned, and do they extend through the entire F region?
(S)2.2.3	What is the rate of movement and time change of the ASF irregularities?
(S)2.2.4	What is the geographical extent of the ASF?
(S)2.2.5	Under what conditions is the ASF scattered signal subject to multipath effects?

Yield optimization questions (U)

(S)2.3.1	How great an effect can be produced at substantial distances (say, 1000 km) from the heating transmitter?
(S)2.3.2	Does the occurrence of wide-band attenuation (WBA) enhance the yield of ASF for a given heating power?
(S)2.3.3	Does the ASF disturbance over Platteville produce a similar disturbance at the magnetic conjugate location in the southern hemisphere?
(S)2.3.4	Does the ASF yield depend on the latitude in which the heating is taking place?
(S)2.3.5	Can the ASF yield be improved by focusing the RF energy into the ionosphere?
(S)2.3.6	Under given ionospheric conditions, how does the ASF yield depend on frequency?

Basic phenomenology questions (U)

(S)2.4.1	Is the phenomenon normally described as "natural occurring spread F" actually a manifestation of ASF from communication or broadcast HF transmitters?
(S)2.4.2	What is the mechanism for WBA, and how does it relate to enhanced IR emission?

Table 5

Realistic experiment list for the questions in Table 5.1 (U)

"P" denotes a primary role for the experiment, "S" a supporting role

Experiments required			Scattering Model 2.1	2.2	2.3	2.4	2.5	Yield Optimization 3.1	3.2	3.3	3.4	3.5	3.6	Basic 4.1	4.2
2.5.1	Satellite transmission	geostationary	P	S	P	S									
2.5.2		orbital	P	P		S									
2.5.3	Aircraft-borne	bistatic HF	S	P	S			S			S	S	S	S	
2.5.4		local sounder				P		P		S	P		P		
2.5.5		remote sounder								P					
2.5.6	Rocket aperture synthesis						P								
2.5.7	Frequency variation of WBA								P				S		P
2.5.8	Mobile heater	latitude scan									P			S	
2.5.9		focusing										P			
2.5.10		frequency opt.											P		
2.5.11		rocket diagnostic													P
2.5.12	Broadcast ASF													P	

(S) 2.5.2 Orbital satellite transmission experiment

(S) This experiment was also described by Bowhill (1970). This would involve the polar-orbiting satellite ISIS-A (apogee 2531 km, perigee 2579 km) at a frequency of 137.95 MHz. This satellite is turned on by command from the University of Western Ontario and the scintillation effects can be observed (if the orbit is carefully selected) at almost any location relative to Platteville. It might be appropriate to consider one experiment looking essentially in the magnetic meridian plane through Platteville at the satellite; one with the receivers located about 500 km to the south (thereby simulating the radar degradation situation); and one with the receivers located to the east of the ASF region. The instrumentation would again be simple interferometer. Again, an approximate 3-month period would be necessary to instrument this experiment.

(S) 2.5.3 Bistatic HF aircraft experiment

(S) To establish realistic cross sections for HF backscatter from ASF, it is proposed that an airplane be equipped with an HF backscatter receiver, compatible with the Raytheon HF backscatter system. With the large powers involved the sensitivity required is not excessive, and only total power measurements are required (there seems little to be gained by Doppler measurements from an aircraft). The arrangement would be to survey the "bright area" produced on the ground by HF illumination of ASF at several frequencies, thereby verifying field alignment and providing a realistic set of cross section data for comparison with scattering models derived from the transmission experiments 2.5.1 and 2.5.2. Since the reflected signal is likely to be detectable over a restricted latitude range (depending on the geometry), it is suggested that the aircraft fly in an east-west zig-zag, at alternating azimuths of 330 and 210 deg, changing direction at the northerly and southerly limits of signal reception. In this way, a complete contour map of field strength will be produced. It is suggested that WSPG would be a suitable initial location for the HF transmitter. Of course, the signal recorded would

be the scattered pulse rather than the direct wave. The time needed to establish this experiment will be approximately 4 months assuming that an aircraft is available.

(S) 2.5.4 Local sounder aircraft experiment

(S) As will be described in Section 4, the AFCRL aircraft-borne ionosonde has shown itself capable of mapping the geographical extent of ASF. This brief but valuable experiment was programmed into an already very full AFCRL schedule. Since this type of measurement has a prime role for questions 2.2.4, 2.3.1, 2.3.4 and 2.3.6 (see Table 5), it is recommended that either (i) the AFCRL aircraft should be re-programmed to IVORY CORAL at the expense of its present auroral program, or (ii) another aircraft should be sought with the same (or better) capability. The aircraft should be used to map the present ASF region in an east-west direction as well as north-south. This type of measurement can easily be combined with experiment 2.5.3 to answer a number of questions (e.g., 2.3.1, 2.3.4 and 2.3.6). Given the availability of the aircraft, this experiment can be mounted within a month.

(S) 2.5.5 Remote sounder aircraft experiment

(S) With the objective of answering question 2.3.3, it seems appropriate to proceed with determining the presence and extent of perturbations of the ionosphere at ~~a point~~ magnetically conjugate to Platteville. It is suggested that a sounder-equipped aircraft (from AFCRL, or elsewhere) based at Buenos Aires, Argentina, could make a series of 10-hour flights to the wes , permitting an hour or two of flight in the vicinity of the ma etic conjugate pe nt. Communication radio silence during an excursion would be e sential to perserve security. It is suggested that ordinary-wave heating be used exclusively at Platteville during this experiment; and the complication involved warrants at least a 1-week period of observation (permitting observations at various times of day and night). About 2 months would be required to set up this experiment.

(S) 2.5.6 Rocket aperture synthesis

(S) In a paper presented at the OHD Technical Review Meeting or March 17, 1971, Villard (1971) presented an idea for using a rocket to determine the direction of a distant HF transmitter using a missile-borne HF receiver. This idea is further developed in section 4 of this report, and will be carried out on a feasibility basis in August 1971. The principle of the experiment is to use coherent reception of an HF signal by a rocket launched from Wallops Island, Virginia, as part of a NASA experiment to determine the angular power spectrum over Wallops Island of signals on 8 MHz, transmitted from California, and scattered from ASF irregularities over Platteville.

(S) 2.5.7 Frequency variation of WBA

(S) Some measurements of WBA have been made by Cohen and Whitehead (1970). These observations are not sufficiently detailed or precise to permit mapping of "radio-reflectivity" (as they call it) as a function of frequency. It is suggested that a careful absorption experiment should be set up using techniques proved during the IGY and IQSY absorption measurement programs, to determine the ionospheric absorption at a series of frequencies between foF2 and the heater frequency. Ordinary-mode polarization should be used for the heater transmitter, because of its increased proclivity to the WBA effect. Careful mounting and calibration of this experiment would probably require about 6 months.

(S) 2.5.8 Mobile heater latitude scan

(S) MITRE

It is suggested that threshold power information for production of ASF would permit using less than 10 units of the module to map the ASF power threshold versus latitude. An aircraft-borne sounder would be a highly desirable adjunct to this experiment, while a ground-based sounder would be a necessity. Magnetic latitudes from 5 deg to 30 deg should be tested in sequence, allowing approximately

2 weeks for erection time, 1 week of experimental operation and a week for tear-down time. Thus, an experiment involving four locations could be completed in approximately 6 months. According to the design document, the delivery and testing would be expected to be completed within 22 months.

(S) 2.5.9 Mobile heater focusing

(S) Among the many antenna arrangements possible for the transportable HF transmitter, one possibility would be the establishment of a high-gain antenna system with larger spacing of the antenna elements (since the length of feeder would not be a problem). One aim could be producing a heated volume no more than 20 km across; by no means out of the question if antennas designed for fixed-frequency operation were used. It is estimated that suitable antennas could be constructed for $100,000 and that the experiment could be mounted immediately following delivery of the mobile heater. An experimental period of approximately 1 month would be required.

(S) 2.5.10 Mobile heater frequency optimization

(S) Since the mobile HF transmitter module is to be designed with relatively rapid frequency-change capability, it would be ideal for the purposes of the frequency optimization experiment. The heater frequency should be solely scanned in steps of about 0.05 of foF2 from about 0.6 foF2 to 1.2 foF2. Again, a vertical-incidence ionosonde would be required in conjunction with this experiment, which would take approximately 2 weeks once the mobile heater was set up.

(S) 2.5.11 Mobile heater rocket diagnostic

(S) If the theory of WBA and its relationship to ASF proves impervious to theoretical attack, it will be necessary to gather additional information concerning it. Setting up the mobile heater at WSPG would permit firing an instrumented rocket payload through the heated region when WBA is present. Suitable rocket instrumentation would consist of:

1. Langmuir probe for electron density fine structure;
2. 6300 A optical sensor for high-resolution airglow experiments;
3. High-sensitivity Faraday cup for non-Boltzmann electron population;
4. AC electric field meter for plasma wave detection.

(S) A series of three of these rockets could be assembled in approximately 9 months, though the time limitation would be primarily that for assembling and deploying the mobile heater.

(S) 2.5.12 Broadcast ASF

(S) The exploration of the potential of broadcast HF transmitters for ASF production should begin with a choice of a transmitter operating below foF2 with high power at a similar latitude to Boulder. While such a transmitter would not normally operate below foF2 for long-distance communication purposes, it could no doubt be specially programmed on and off during its idle time, and the incidence of ASF measured with a portable ionosonde (or aircraft ionosonde). Most VOA stations have frequencies intended for night use which, in the day, would be suitably low relative to foF2.

(S) This type of experiment would be easy to program if permission of the relevant agency (such as VOA) were obtained. It would take no more than 3 months to set up the experiment, and 1 month to determine whether a suitable result had been obtained.

2.6 Overall Plan for IVORY CORAL Activities (U)

(S) The extraordinary significance for defense applications of the results obtained in IVORY CORAL warrants an accelerated program to determine its exact systems applicability, and the material of this section is predicated upon that approach. The proposed program incorporates a series of cutback points at which the program can be decelerated if the systems applications prove less significant than now appears likely.

(S) On examination of the uncertainties involved in ASF and WBA, it seems that the first priority must be given to formulation of a good scattering model for ASF, following which systems studies can be carried out. This philosophy lies behind Table 6. FY 1972 is seen as a period during which a comprehensive set of scattering models and experiments will be carried out leading to a finalized scattering model by June 1972. System studies will then be carried out during FY 1973 leading to a decision in June 1973 as to the systems in which the phenomena are most applicable. Progress will be continually monitored during FY 1973, to permit modification of the rate of effort in accordance with the significance of the results obtained.

(S) During calendar 1973, comprehensive yield optimization studies will be made, with firm conclusions on optimum configurations around March 1974. By summer 1974, it should be possible to demonstrate hard applications capabilities to the interested agencies, leading to the development of two or three operational systems during 1975. In fall 1975, therefore, the systems developed could be turned over to the relevant agencies; and progress monitored by ARPA in an advisory capacity during the remainder of FY 1976. At that time, it will be appropriate to consider preparation of a second-generation system.

(S) As support for this set of milestones, the following priorities and scores have been assigned to the various questions set out in Table 4:

First priority (Score 3) 2.2.1, 2.2.2, 2.2.4, 2.3.1, 2.4.1

Section priority (Score 2) 2.2.3, 2.3.2, 2.3.3, 2.4.2

Third priority (Score 1) 2.2.5, 2.3.4, 2.3.5, 2.3.6

(S) For each experiment in Table 5, the scores of the various questions it purports to answer have been cumulated, using the multiplier of 2 for questions where the experiment plays a prime role, and 1 where it plays a supporting role. The resulting scores are shown in Table 7, which has been the basis of the ordering of priorities for the various experiments.

Table 6

Milestones for IVORY CORAL (U)

(S) Fiscal 1972	--	Scattering model studies
(S) June 1972	--	Finalize scattering model
(S) Fiscal 1973	--	System studies
(S) June 1973	--	Finalize system conclusions
(S) Calendar 1973	--	Yield optimization studies
(S) March 1974	--	Finalize yield conclusions
(S) Summer 1974	--	Demonstrate applications capabilities
(S) Fiscal 1975	--	Develop 2 or 3 operational systems
(S) Fall 1975	--	Turn over to operational agencies
(S) Fiscal 1976	--	Monitor progress and prepare second-generation system

Table 7

Total scores by experiment number (U)

Experiment	Score
5.1	16
5.2	22
5.3	20
5.4	18
5.5	4
5.6	2
5.7	9
5.8	5
5.9	2
5.10	2
5.11	4
5.12	6

Totals 13 for mobile heater

(S) As an illustration, a detailed timetable has been set out for FY 1972 in Table 8; similar tables can be prepared for subsequent fiscal years. Granted the strong likelihood that a critical defense application exists for the IVORY CORAL phenomenon, the determination of a sufficiently good scattering model by the program shown in Table 8 fully warrants an accelerated approach; accompanied by a detailed survey of potential systems applications in readiness for the FY 1973 program.

Table 8

Detailed timetable for fiscal year 1972 (U)

(S) July 1971	Initiate satellite transmission experiments Initiate bistatic HF instruments for aircraft Arrange for aircraft availability starting October 1, 1971 Initiate WBA frequency variation instrumentation Initiate mobile heater procurement
(S) September 1971	Initiate broadcast ASF program
(S) October-December 1971	Carry out orbital satellite transmission experiment with support of aircraft bistatic and ionosonde measurements during October and November
(S) December 1971	Carry out broadcast ASF experiment with support of aircraft ionosonde
(S) January 1972	Move satellite transmission experiment to geostationary location
(S) January-March 1972	Carry out WBA frequency-variation experiment
(S) February-March 1972	Carry out geostationary satellite transmission experiment with support of aircraft ionosonde
(S) April 1972	Initiate and carry out remote aircraft experiment Initial data review for scattering model
(S) June 1972	Finalize scattering model

3. AIRBORNE EXPERIMENT (U)

(S) The objective of this experiment is to determine whether the occurrence of spread-F irregularities over an artifically heated portion of the F2 region generates corresponding irregularities at the magnetic conjugate point, which have similar properties in the scattering of HF and VHF radio signals.

(S) It appears evident that the irregularities of ionization in the heated region must have electric fields associated with them, which produce ionization convection by motor action. These electric fields must be conducted along the lines of the earth's magnetic field to the magnetically conjugate ionosphere. Here, they will convect the ionization of the conjugate ionosphere. Whether this conjugate convection gives rise to small-scale gradients of ionization hinges upon the exact mechanism by which the gradients are produced in the heated region. No firm answer is presently available, so it is necessary to rely on a purely phenomenological approach.

(S) Since the conjugate point to Boulder, Colorado, is in a remote area of the South Pacific Ocean, it cannot be investigated except by a mobile sensor. Of these, by far the most convenient is an aircraft-borne ionosonde. Accordingly, it was decided to determine the feasibility of using such an ionosonde as a sensor for the spread-F phenomenon by an experiment carried out directly under the heated region.

(S) A secondary objective was the determination of the horizontal extent of the F2 layer over which the spread-F effects was visible.

(S) Through contact with Dr. G. J. Gassmann of the Ionospheric Physics Laboratory of AFCRL, the AFCRL aircraft was flown over the Platteville area on March 29 and 31, 1971. The aircraft was supervised by Dr. Gassmann; and the ground-based operations were in the charge of Mr. E. J. Violette of the Office of Telecommunications.

(S) At an initial planning meeting with Dr. Gassmann and Dr. W. F. Utlaut, a magnetic north-south path was laid out over two VOR beacons passing about 5 km east of Platteville. Five reference points were selected along this line, numbered consecutively passing from south to north as follows:

1	--	
		60 km
2	Denver VOR	
		35 km
	Platteville	
		38 km
3	Gill VOR	
		60 km
4	--	
		60 km
5	--	

Distances are indicated between the successive points.

(S) The experiment matrix is shown on Figure 1. In each case, the aircraft scanned in a magnetic north-south direction for about a three-hour period in the morning. The appropriate times at which it passed each of the points 1 through 5 are indicated on Figure 1. The heating transmitter was at 8.8 MHz on March 29, radiating extraordinary mode. On March 31, the transmitter radiated ordinary mode on 6.82 MHz. In each case, the aircraft scans continued both before the onset of heating and following its termination.

(S) Time has not yet permitted the detailed analysis of these data. However, the following conclusions can be drawn:

1. All of the effects visible on ground-based ionosondes can also be seen on the aircraft ionosonde. Interference from broadcast transmitters is not as serious as had been anticipated.
2. With X-wave heating (above foF2) extra traces were seen to at least 120 km north and 95 km south of Platteville. These traces were generally parallel to the usual O and X traces, sometimes higher in critical frequency, sometimes lower.

AIRCRAFT 3131 EXPERIMENT MATRIX

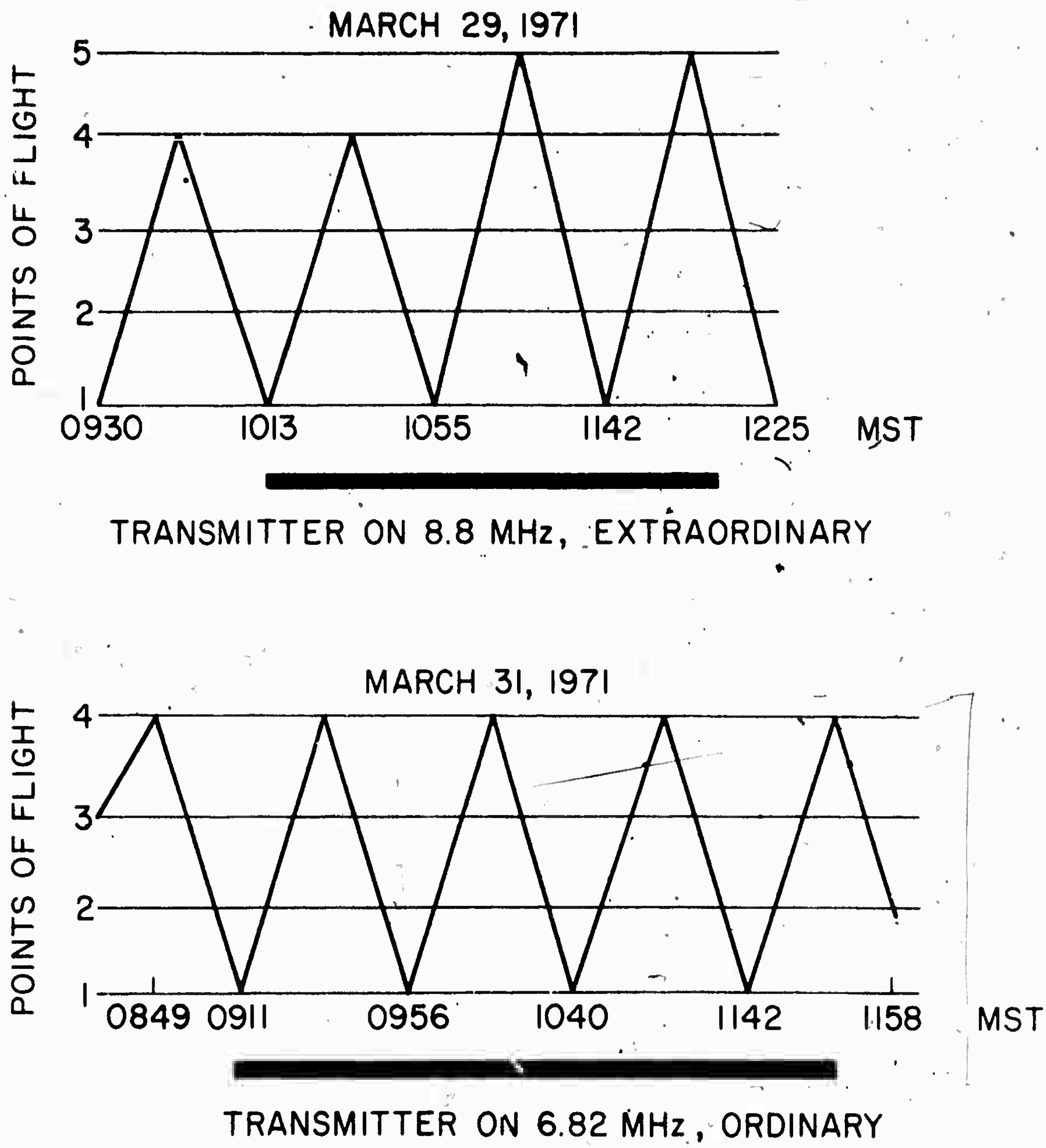

Figure 1

3. The most prominent feature with O-wave heating was range spreading on both the O and X traces. However, the characteristic absorption of the O-wave was also visible between the heating frequency and the (higher) foF2.

4. The effects appeared to maximize at the point where the heating was theoretically greatest, and to extend about 100 km either side. An exception was the O-wave absorption, which appeared to be restricted to a smaller zone surrounding the heating transmitter.

5. It appears that it will be feasible to use the aircraft-borne ionosonde for investigation of the magnetic conjugate region. However, since it is extensively committed for auroral studies at present, this would require a reprogramming of its mission.

4. PLANNED ROCKET EXPERIMENT (U)

(S) Following a suggestion by Villard (1971) that a missile receiver telemetering the phase and amplitude of a distant CW transmitter could be used for synthesis of a very large aperture for DF purposes, it seemed appropriate to consider an experiment to verify this possibility as part of an existing plan for rocket experiments calling for measurements of the field strength by an HF radio receiver carried in a Nike-Apache rocket ascending to 200 km altitude over Wallops Island, Virginia, in August 1971. The purpose of the experiment is the measurement of the differential absorption (of the O and X waves) and the Faraday rotation of a CW signal radiated from polarized antennas located close to the launch point. Amplitude of the signal received at a magnetic dipole antenna in the rocket is transmitted to the ground recorded. Frequency used varies from 2 to 8 MHz.

(S) One of the rockets to be launched in this series is scheduled for firing at two hours after local sunset. At that time, it is proposed to radiate two signals from the ground to the rocket. One, at 8 MHz, (called signal A hereafter) will be radiated from the launch point direct to the rocket, with ordinary polarization, and with a controllable amplitude. The second (hereafter referred to as signal B) will be radiated at a frequency 500 Hz higher, from the SRI transmitting array in California, pointed at the heated region over Boulder. The interference between signals A and B at the rocket antenna at any given moment will give a 500 Hz beat frequency, which will be transmitted to ground and recorded, together with a 500 Hz reference from a crystal-controlled oscillator. The amplitude of signal A will be controlled so as to maintain an approximate 30% modulation percentage of the 8 MHz signal. The amplitude of the 500 Hz modulation will then give the amplitude of signal B, and the

relative phase of signals A and B will be given by the relative phase of the modulation and the 500 Hz reference signal.

(S) Fourier analysis of the signal during each 10 km segment of the rocket trajectory will then give the angular spectrum of signal B for that particular geometry. In way, it will be possible to map the propagation character-istics for signal B (including enhanced MUF effects). Mounting of this ex-periment would involve little expense, and would also permit verification of the advanced concept of aperture synthesis by means of rocket-borne receivers.

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13. ABSTRACT

CLASSIFIED ABSTRACT

(S) Comments on possible defense applications of artificial spread F (ASF), and wideband attenuation (WBA), re-discussed and related to a possible five-year plan for the IVORY CORAL program. The preliminary results of an airborne experiment are given. The purpose of which was to determine the feasibility of a conjugate point experiment on ionospheric heating.

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